Geostationary Carbon Process Mapper (GCPM)

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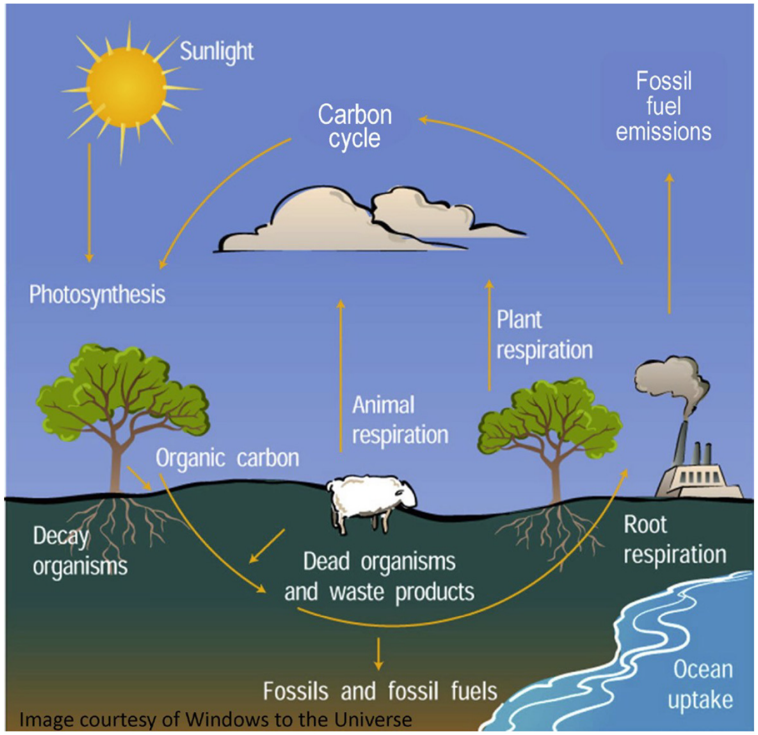
Outline

- Carbon Cycle Observation
- Science from Geostationary Orbit (GEO)
  - Complementing other observations
  - High spatial and temporal coverage
  - High resolution CO_2, CH_4, CF (chlorophyll fluorescence), and CO measurements
- GEO Measurement Requirements
- GeoFTS Instrument Concept
- GCPM Mission Concept
- Summary

Carbon Cycle Observation

- Carbon exchanges between carbon reservoirs form the carbon cycle
- Spatial and temporal gradients in atmospheric CO_2 and CH_4 may be inverted to estimate fluxes
  - Flux inversion has large uncertainties, since applied to under-measured systems
  - Typically conducted for single species, lacking information to disentangle signals from natural/anthropogenic processes
  - Local signals are immediately transported by weather systems



The carbon cycle

- Challenge for better understanding of the carbon cycle is twofold:
  - Increase spatial and temporal density of measurements to better fit into models used in inversion framework
  - Measure key variables that will enable models to disentangle fluxes from natural and anthropogenic processes

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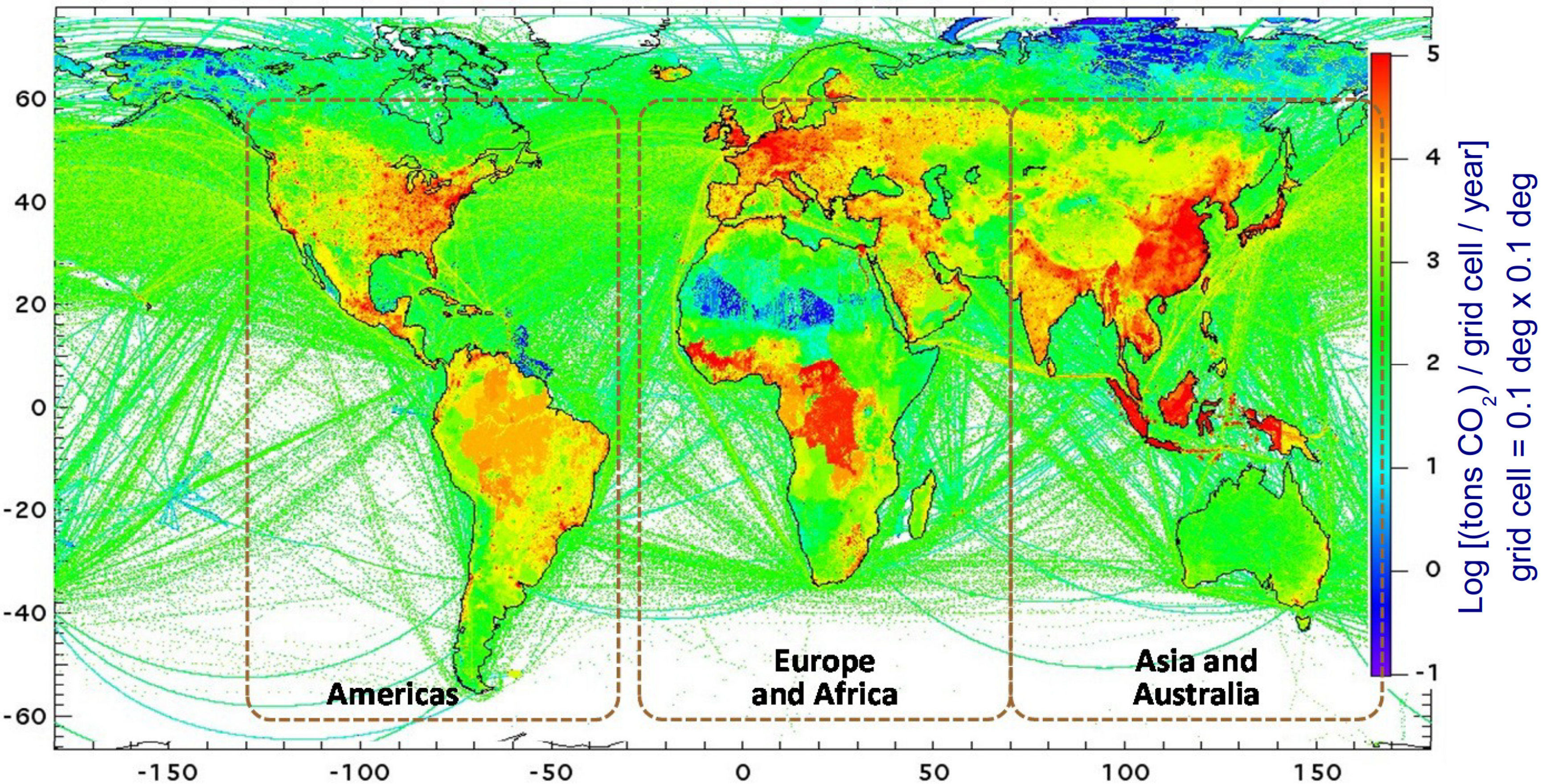
Science from GEO

- Measurements from ground, airborne, and low earth orbit (LEO) platforms do not provide full range of spatial and temporal measurements needed for a complete understanding of carbon cycle processes over large geographic regions
- Need simultaneous, high resolution measurements of CO_2, CH_4, CO, and CF in near IR from GEO
  - Fine time scale (minutes, hours, days)
  - Small spatial scale (few km) over continental size regions
- Continuous stare from GEO at any region in field of regard enables flexible mapping capability with maximum probability of cloud avoidance
- High spatial and temporal resolution from GEO enables:
  - Understanding of processes which have time scale of minutes to hours
  - Minimizes transport error, spatially matched to hourly transport (~8 km)
- **GCPM will provide process-based understanding of carbon cycle variability, covering up to 1/3 of the globe in its observation**

Science from GEO

Anthropogenic CO_2 Emissions



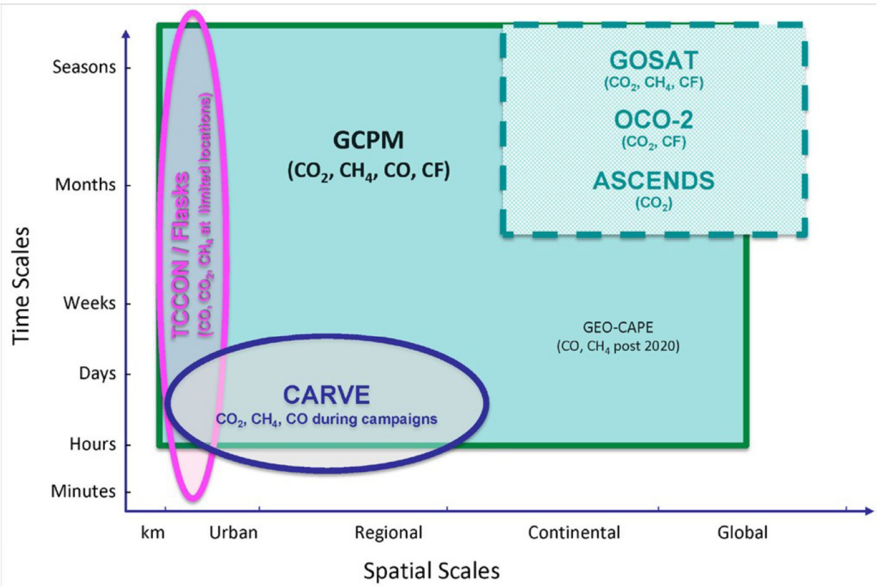
Source: EC-JRC/PBL. EDGAR version 4.2. http://edgar.jrc.ec.europa.eu/, 2011

Almost any location in GEO would provide access to observe the spatial and temporal variations in emissions over mega cities, diurnal uptake and release of greenhouse gases in cropland regions, the dynamic response of vegetation to varying illumination and stress conditions, and atmospheric transport and mixing processes.

Science from GEO

Complementing other observations

- Ground-based networks provide frequent samples over limited geographic locations
- Airborne platforms provide regional coverage, but only during campaigns
- LEO satellites provide global observations but not frequent enough to capture fast carbon cycle processes over vast geographic areas



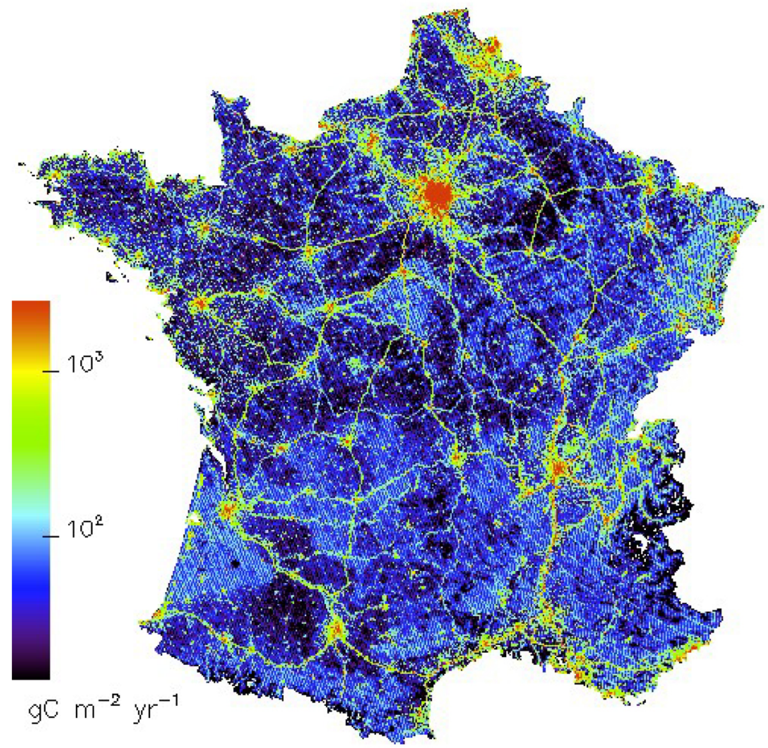
Carbon cycle observations

- GCPM measurements will fill the gaps in current observations while covering more species
- Together with current LEO observations of polar regions, the GEO / LEO combination will be a powerful tool for quantifying the global carbon budget and anthropogenic emissions

Science from GEO

High spatial and temporal coverage

- Timely estimates and verification of changes in the global patterns of fossil fuel combustion are essential
  - For evaluation of socio-economic conditions
  - For climate model projections
- Measurements from GEO several times per day with <8 km ground sampling resolution will provide extraordinary details of anthropogenic emissions across urban areas



Simulated CO_2 map of France (P. Ciais, et al, 2010)

- Example: high spatial resolution measurements make the urban dome over Paris and large power plant plume over Lyon clearly identifiable
- **GCPM will resolve diurnal variability of CO_2 on city to continent scales**

Science from GEO

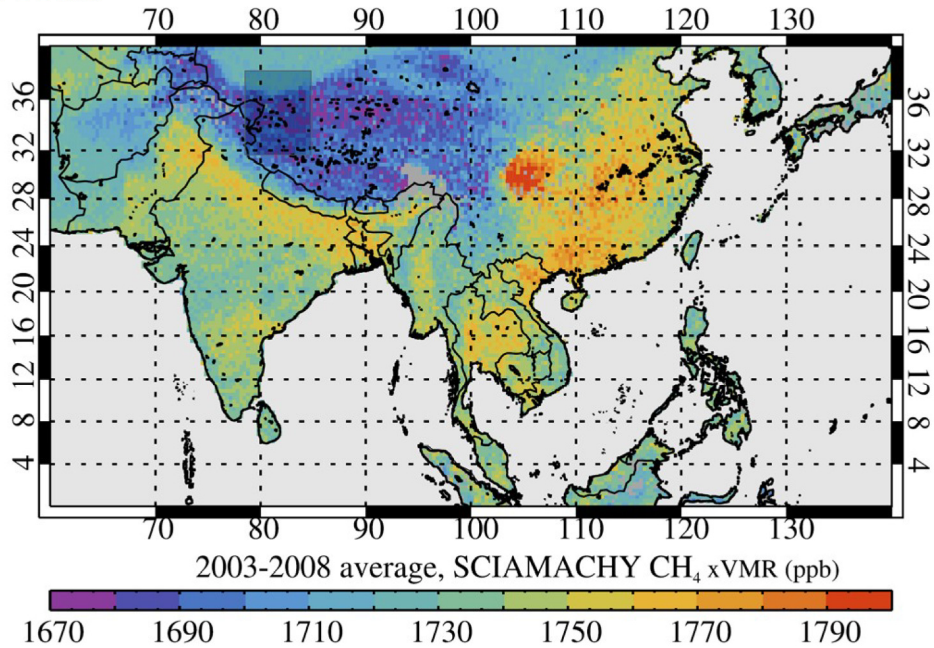
High resolution CO_2 measurements

- CO_2 is the most important anthropogenic greenhouse gas
- Fundamental questions still remain: are continental regions net carbon sources or sinks?
  - Plants absorb roughly as much CO_2 through photosynthesis as they emit thought respiration and dead plant material decay or combustion
  - Net ecosystem exchange (NEE) varies around zero, but uncertainties exist
  - Many measurements per day are required to understand and predict daily patterns of NEE
- GEO measurements many times per day provide information about how the fluxes of CO_2 vary on diurnal, synoptic, seasonal, interannual time scales
  - Reduce flux uncertainties on scales appropriate to resolve regional variations

Science from GEO

High resolution CH_4 measurements

- CH_4 is the second most important anthropogenic greenhouse gas
- Released as part of biological processes in low oxygen environments (swamplands, rice productions)
- Abundance of atmospheric CH_4 has nearly tripled since the industrial revolution, contribution from individual sources remains unclear



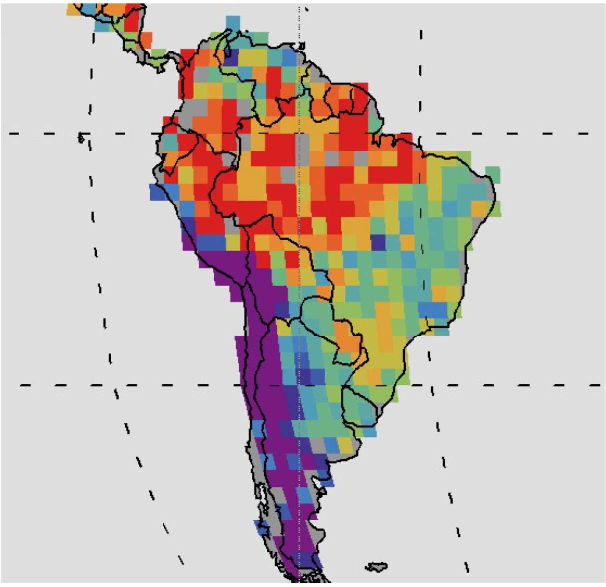
CH_4 map derived from SCIAMACHY satellite data, showing high methane column average in southern and eastern Asia (C. Frankenberg, et al, 2011)

- Simultaneous high resolution, high frequency measurements of atmospheric CO_2, CH_4, CO, and CF will make it possible to distinguish anthropogenic and biogenic sources of CO_2, and CH_4, revealing how secular trends in CO_2 and CH_4 correlate with key physical, biological, and socio-economic markers

Science from GEO

High resolution CF and CO measurements

- Remote sensing of terrestrial vegetation is a vital tool for trend monitoring and carbon flux estimation
  - Traditional methods using satellite data mainly based on indices
  - Chlorophyll fluorescence observation offers a more direct insight into photosynthesis
  - Daily observations from GEO will provide greater insight into dynamic response of vegetation to varying illumination and stress conditions

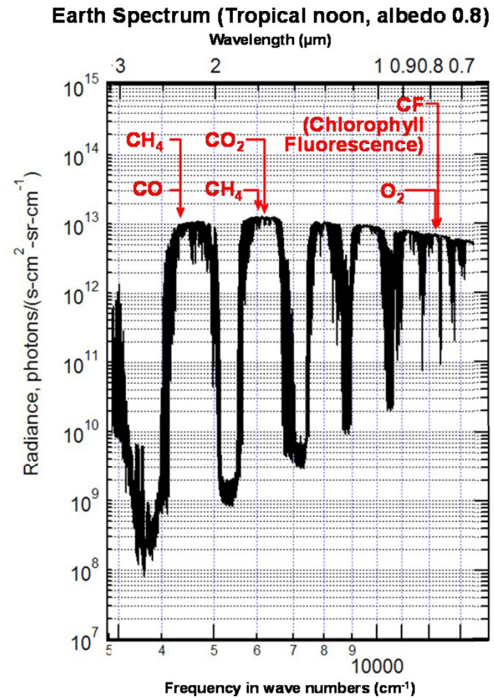


There is limited resolution CF information available from current LEO satellite data (provide by C. Frankenberg)

- Measurements of CO, a strong tracer of fossil fuel combustion, can help identify sources of CO_2 and CH_4
  - Used to distinguish combustion sources of CO_2 from terrestrial sources and sinks
  - Used to distinguish CH_4 sources: wetland (low CO), biomass burning (high CO)

GEO Measurement Reqs.

- GCPM uses imaging spectroscopy for atmospheric composition remote sensing
  - Acquisition of images that have a spectrum of the energy arriving at the sensor at each spatial resolution element
  - Spectra used to derive information on the composition of trace gases and aerosols in the atmosphere
- GCPM uses three spectral regions to measure all species (CO_2, CH_4, CO, CF)
- O_2 A-band is also retrieved, used to determine aerosol properties and reduce retrieval uncertainties
- Ground sampling distance (< 8 km) matched to typical airmass transport (~8 km/h)
- Hourly observation ensures coverage of fast carbon cycle processes



Species	CO_2	CH_4	CO	CF	O_2
Spectral Window(s) (cm^{-1})	6190-6380	4210-4260 5950-6100	4210-4260	13175-13225	13000-13170
Spectral Resolution (cm^{-1})	0.3	0.3	0.3	2 (0.1 nm)	0.6
Precision (1σ)*	0.33%	1%	10%	5%	0.33%
Vertical Resolution	Column abundance				
Field of Regard	+/- 8.6 degrees from nadir				
Ground Sampling Distance	< 8 km at nadir				
Sampling Interval	~ hourly				
Sampling Period	~ 12 daylight hours per day for ~ 2 years				

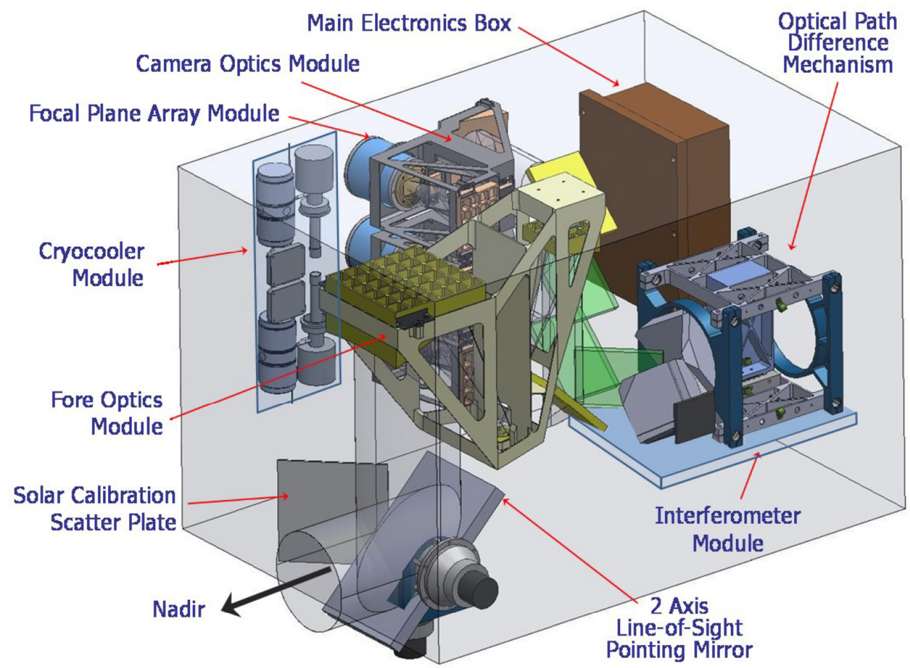
* Expressed as percent of dry air mole fraction (except for CF which is expressed as absolute fluorescence signal over background reflected radiance)

GEO Measurement Summary

- **The GCPM provides fundamental advances in space-based remote sensing of carbon cycle processes**
- Complete, contiguous continental scale mapping with a high spatial resolution (4km x 4km at nadir)
- Hourly/daily revisit frequency for detection of fine details in diurnal photosynthetic cycle
  - Measuring evolution of urban domes
  - Accurately resolving atmospheric transport
- Simultaneous measurement of the CO_2, CH_4, CO, CF geophysical suite
  - Enables disentanglement of natural and anthropogenic contributions to the atmospheric carbon concentrations
  - Minimizes uncertainties in the flow of carbon between the atmosphere and surface since they place constraints on both biogenic uptake and release as well as combustion emissions

GeoFTS Instrument Concept

- GCPM uses a single instrument - “Geostationary Fourier Transform Spectrometer” (GeoFTS)
  - Imaging spectrometer based on Michelson interferometer design
  - “Camera” instead of traditional detector
  - Pictures recorded at high frame rates; path difference continuously varied
  - Fourier transform of each pixel recorded yields spectrum at observation

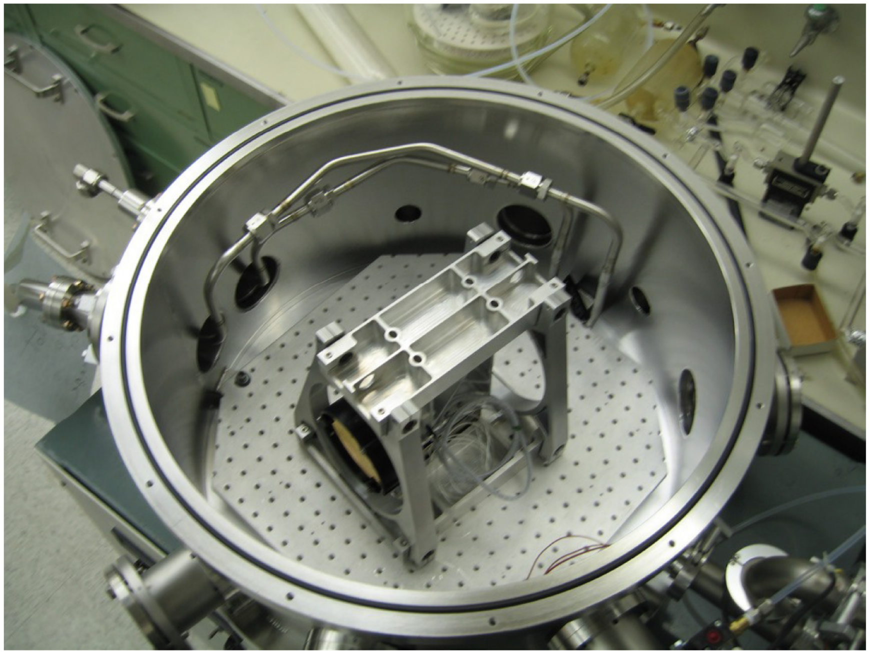


GeoFTS opto-mechanical design is modular and uses high TRL components

- Instrument concept is 60 kg, half meter cube size configuration
- Spectral resolution of interferometer controlled by optical path difference mechanism
- Uses three focal plane arrays, each designed for specific spectral region

GeoFTS Instrument Concept

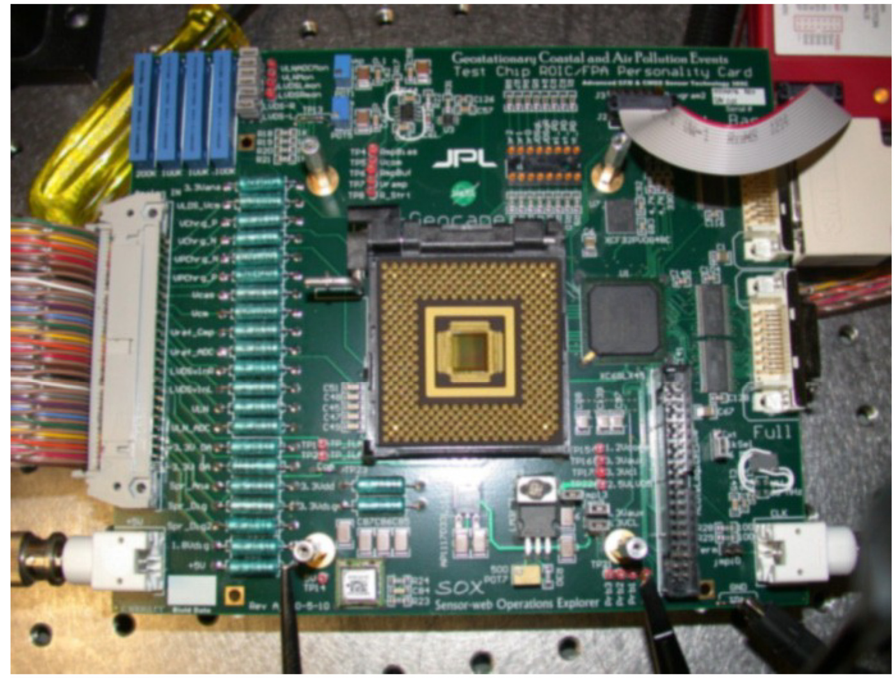
- The optical path difference mechanism (OPDM) is a friction-free flexure-based design
  - Does not require lubricants
  - Has no inherent wear-out risk
- Full size life test unit has completed over 2.5 million cycles under flight like conditions (hard vacuum, -100 °C)
  - Equivalent to four years of operation in space (2x mission life)
  - No discernible changes in mechanism behavior
- With cube corner mirror, OPDM can provide up to 10 cm of optical path difference (GCPM requires only 3 cm)



OPDM, shown inside test chamber

GeoFTS Instrument Concept

- Using a cryocooler, focal place arrays (FPAs) are cooled to 220 K
- Each FPA has identical read out integrated circuit (ROIC) with different detector material hybridized on top
- ROIC is developed by JPL
  - 128x128 60 um pixel
  - ADCs and charge amplifiers in each pixel
  - 14 bit resolution
  - Up to 16 kHz readout



128x128 ROIC test board

- Test ROIC will be hybridized with SiPIN diode detector array (Raytheon) to be flown on GRIFEX CubeSat mission in ~2014 (U. Michigan / JPL)
- FPGA-based system will interface with FPAs to acquire data, perform encoding and compression, and transmit to spacecraft for downlink

GeoFTS Instrument Concept

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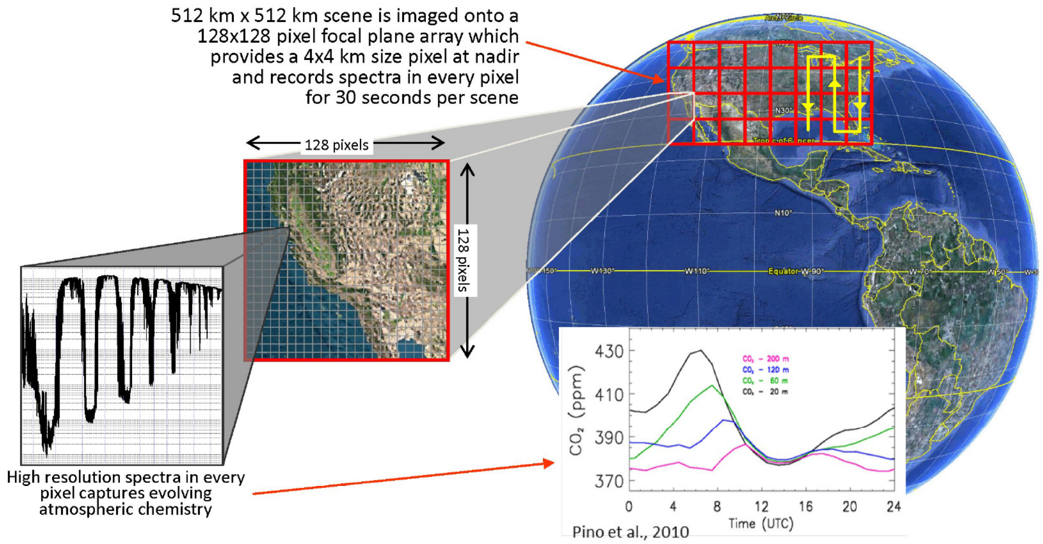
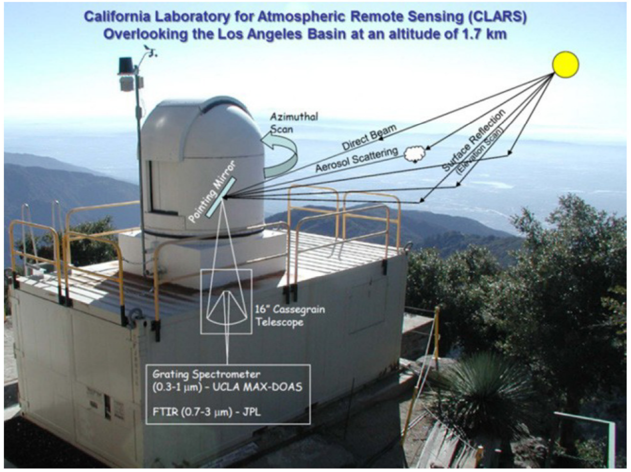
- GeoFTS instrument has its own line-of-sight pointing system
- Each of three FPAs cover a 512 km square scene at nadir
  - 30 sec scan time per scene
  - 16 minute coverage of continental U.S.



GeoFTS observation scenario

- GCPM type of spatial and temporal mapping has been demonstrated by measurements being acquired with CLARS FTIR spectrometer
  - CLARS makes CO_2 measurements over Los Angeles basin several times per day
  - GCPM maps would be similar, but on a larger, continental scale

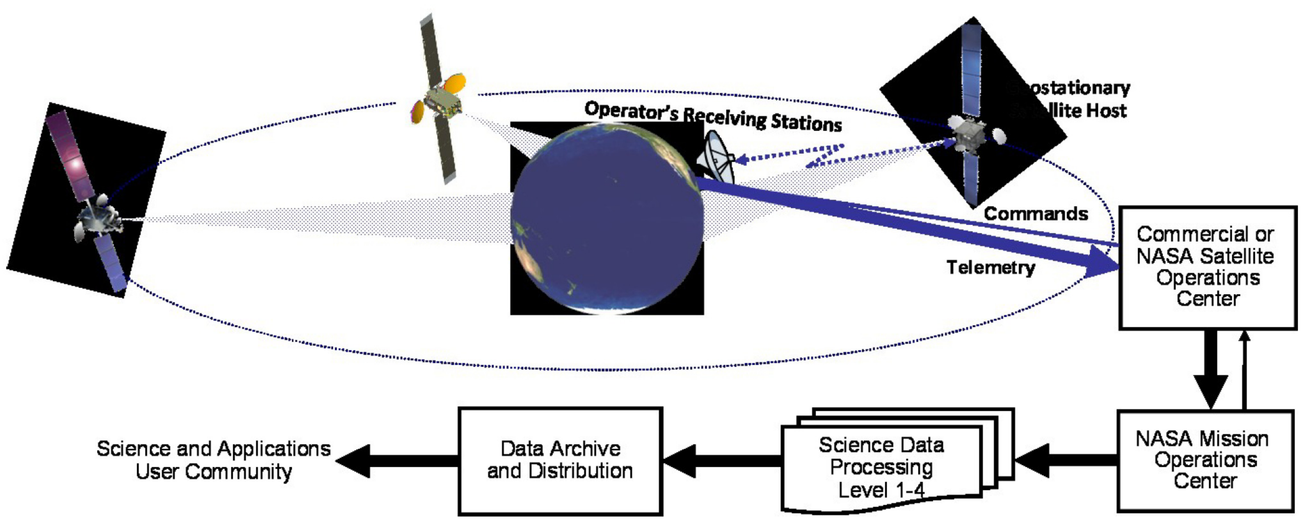


GCPM Mission Concept

- Dedicated mission approach is expensive – involves buying the GEO compatible spacecraft, large launch vehicle, and developing dedicated ground operations center
- GEO hosted payload approach is far less expensive
  - Government payload “hosted” as a secondary payload on a commercial GEO communications satellite mission
  - Leverage already planned satellite bus, launch vehicle, and operations center
  - Missions can be planned and implemented in shorter cycles
- Payload provider pays for
  - Integration of payload with spacecraft
  - Resource usage
    - Power
    - Launch services
    - Operations

GCPM Mission Concept

- GeoFTS design provides excellent compatibility with any GEO spacecraft
  - Small, self-contained, as independent of spacecraft as possible
  - Few simple spacecraft interfaces
  - Can be shut off at end of life (designed for two years of operations)
- Concept of operations permits continuous direct data transfer from GeoFTS instrument to ground receiving stations
  - Data is transmitted from operator's ground stations to GeoFTS operations center
  - Data is distributed to the science and applications communities



Summary

- GCPM is an earth science mission to measure key atmospheric trace gases related to climate change and human activity
- Understanding of sources and sinks of CO_2 is currently limited by frequency of observations and uncertainty in vertical transport
  - GCPM improves this situation by making simultaneous high resolution measurements of CO_2, CH_4, CF, and CO in near-IR, many times per day
  - GCPM is able to investigate processes with time scales of minutes to hours
- CO_2,CH_4, CF, CO selected because their combination provides information needed to disentangle natural and anthropogenic sources/sinks
- Quasi-continuous monitoring effectively eliminates atmospheric transport uncertainties from source/sink inversion modeling
- GCPM will have one instrument (GeoFTS), hosted on a commercial communications satellite, planned for two years operation
- **GCPM will affordably advance the understanding of observed carbon cycle variability improving future climate projections**

Acknowledgments

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